

Liquid Crystal on Silicon Wavefront Corrector

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A low cost, high resolution, liquid crystal on silicon, spatial light modulator has been developed for the correction of huge aberrations in an optical system where the polarization dependence and the chromatic nature are tolerated. However, the overall system performance suggests that this device is also suitable for real time correction of aberration in human eyes. This device has a resolution of 1024×768 , and is driven by an XGA display driver. The effective stroke length of the device is 700 nm and 2000 nm for the visible and IR regions of the device, respectively. The response speeds are 50 Hz and 5 Hz, respectively, which are fast enough for real time adaptive optics for aberrations in human eyes. By modulating a wavefront of 2π , this device can correct for arbitrary high order wavefront aberrations since the 2-D pixel array is independently controlled by the driver. The high resolution and high accuracy of the device allow for diffraction limited correction of tip and tilt or defocus without an additional correction loop. We have shown that for every wave of aberration, an 8 step blazed grating is required to achieve high diffraction efficiency around 80%. In light of this, up to 125 waves peak to valley of tip and tilt can be corrected if we choose the simplest aberration. Corrections of 34 waves of aberration, including high order Zernike terms in a high magnification telescope, to diffraction limited performance (residual wavefront aberration less than $1/30\lambda$ at 632.8nm) have been observed at high efficiency.

Liquid Crystal on Silicon wavefront corrector

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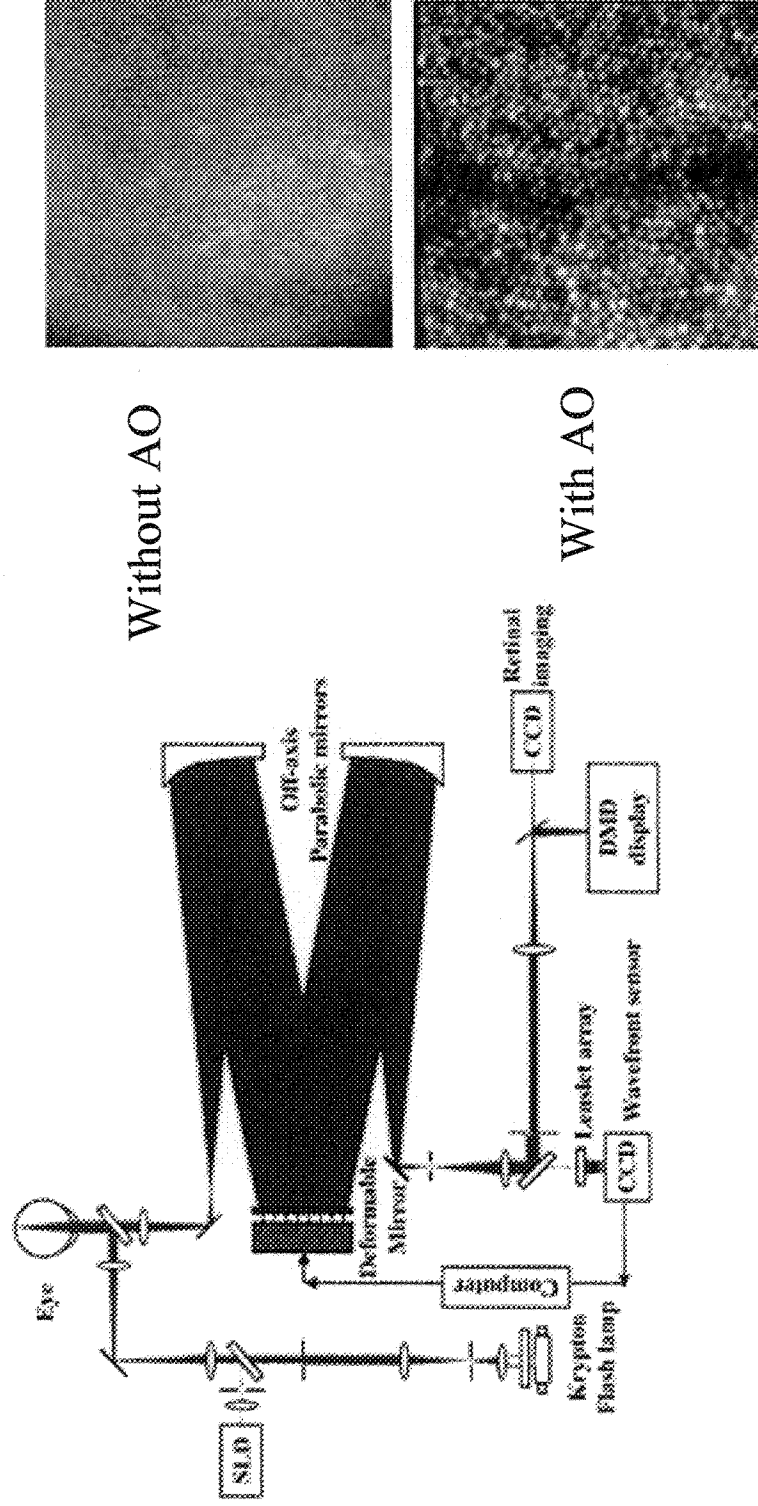
NASA Glenn Research Center, Cleveland, OH 44135

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Outline

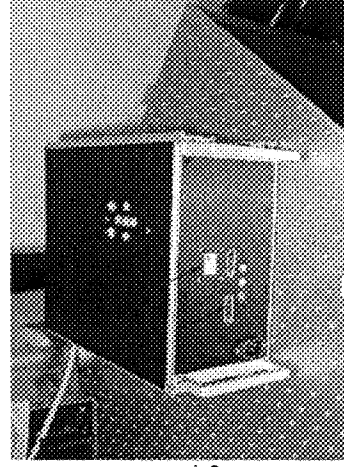
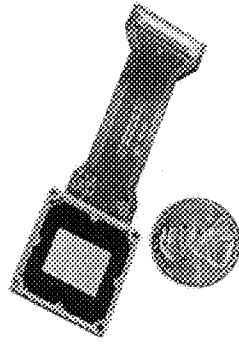
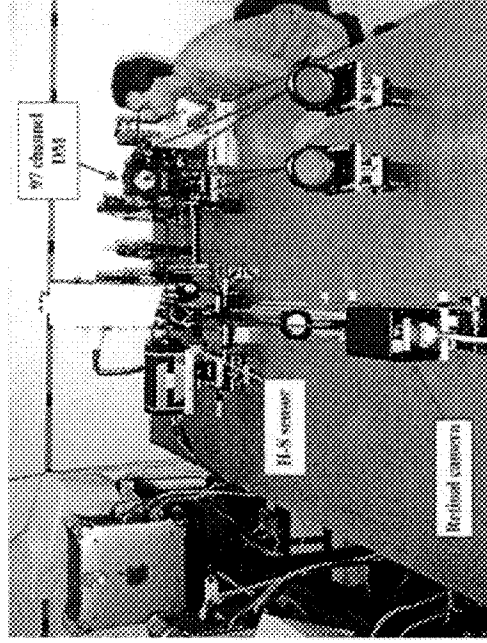
- LCoS SLM Vs. MEMS or Deformable Mirror
- Basics of Liquid Crystal on Silicon (LCoS) Spatial light modulator (SLM)
- Light propagation in LCoS
- Chromatic effect in diffractive wavefront compensation
- Performance of LCoS SLM for wavefront correction

Adaptive Optics (AO) for diffractive retina imaging in Prof. David William's Lab



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What is the benefit to replace DM with LCoS SLM



10^3 cost reduction, **10^3** resolution increase,
 potential portable system, simplified driving
 scheme

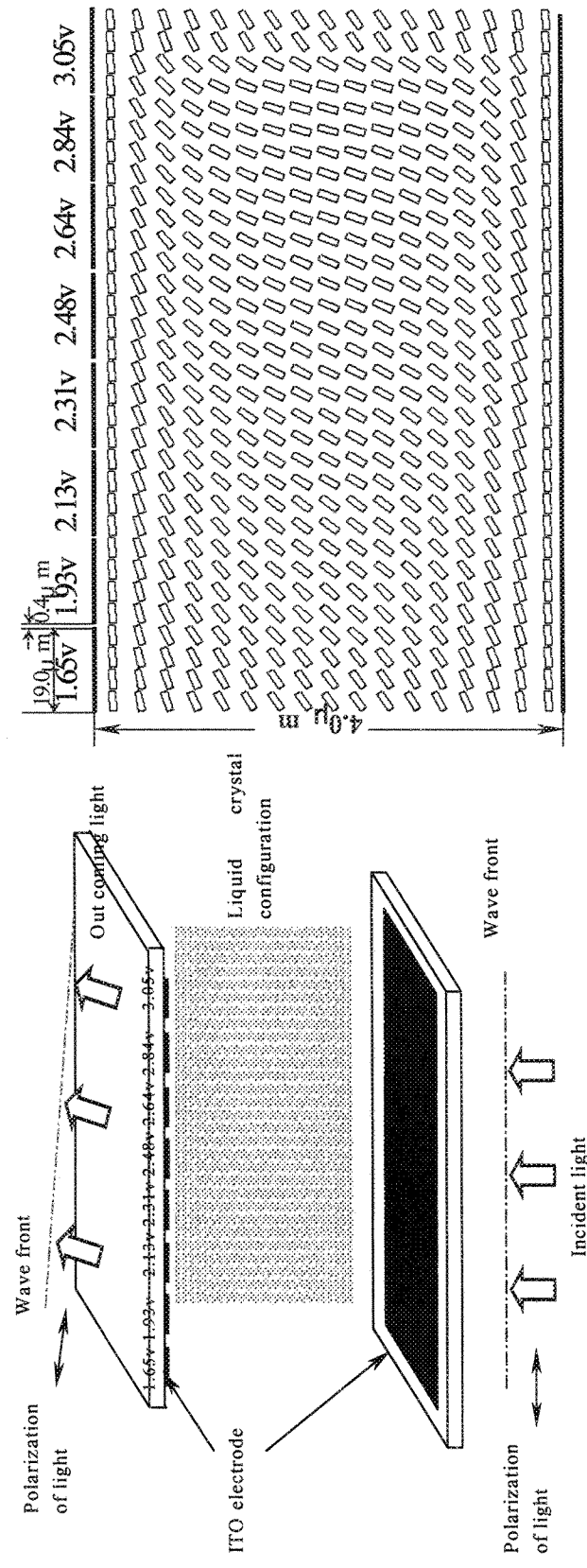
Aberration simulator for patient to
 see the effect of refractive surgery
 before surgery.

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LCoS SLM vs Deformable Mirror

	Pros	Cons
LCoS SLM	<\$3000 with driver, light weigh, low profile resolution > 1024*768 stroke: up to 2.5 um (no limit with wavefront wrapping) no inter-pixel coupling Aperture 20mm*15mm Low driving voltage 0~5v	Speed 50 Hz for 1 um stroke Reflectivity 80% (good enough for aberration correction in human eye)
MEMS DM*	Aperture 3.3 mm, 10 mm High reflectivity >95% Speed 6.6 KHz	> \$250,000/ batch without driver less than 2 um < resolution 12*12 32*32 15% Inter-Pixel coupling, High driving voltage, expensive driver
Xinetics DM	1~2KHz 349 Actuators	> \$1000/ Actuator Clear Aperture 148.6mm

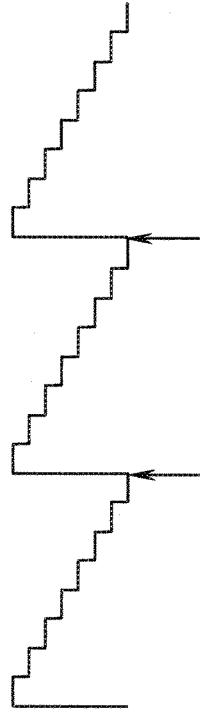
* Boston Micromechanics, SPIE Proc Vol. 5162, p70, 2003



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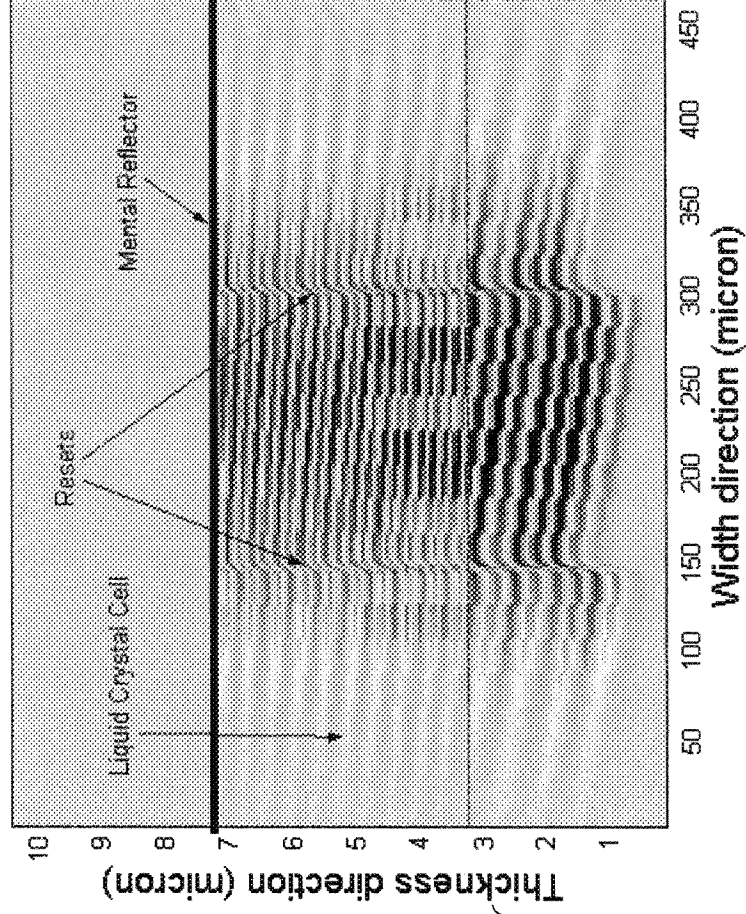
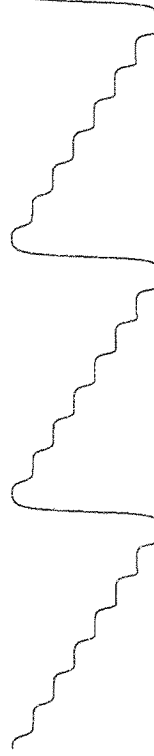
Light Propagation in LCoS

Ideal stair like blazed gratings



1st order resets

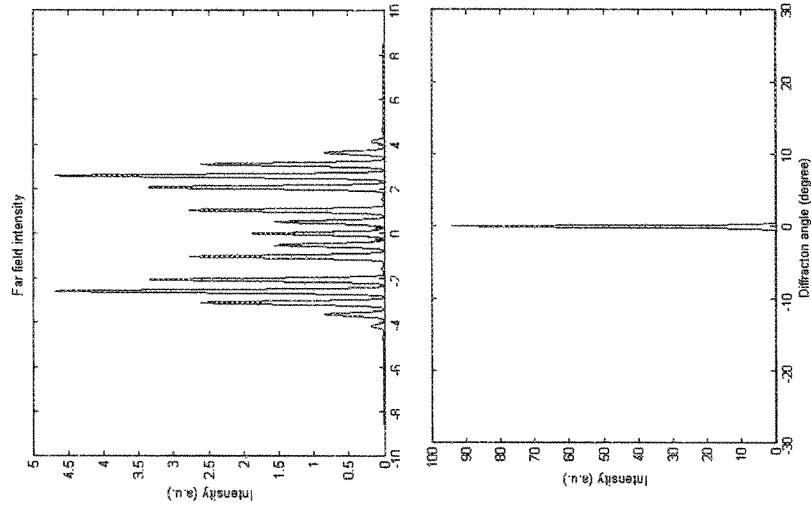
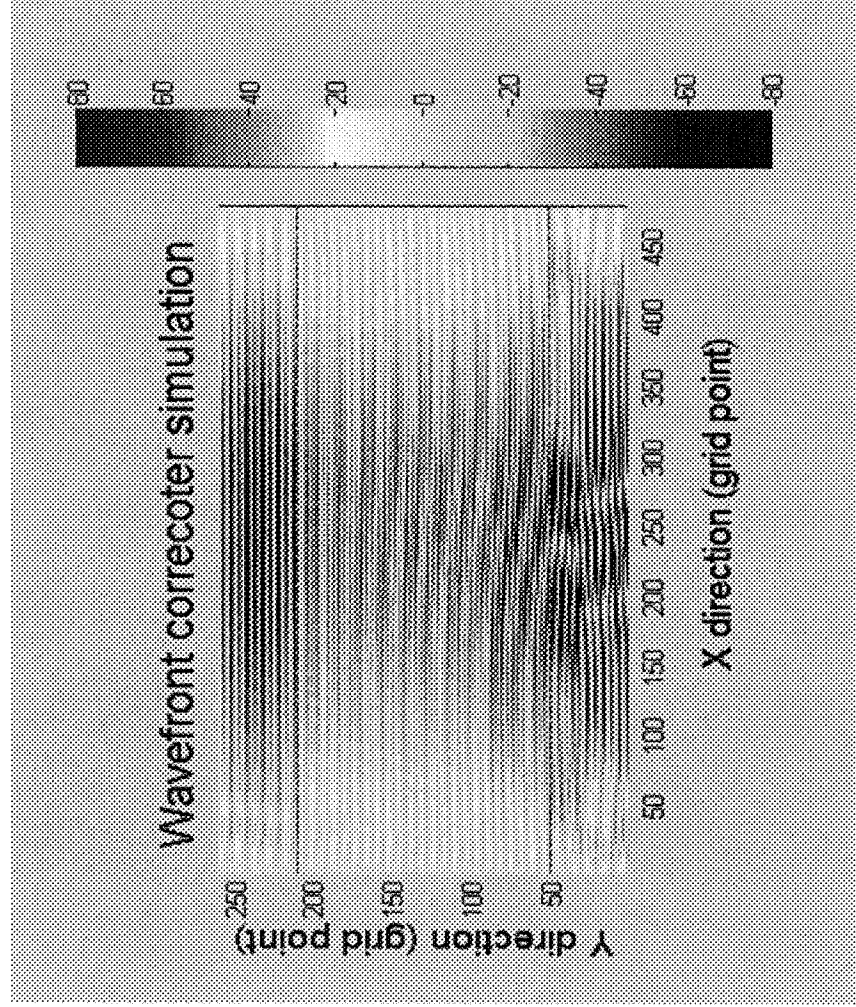
simulated stair like blazed gratings formed by LC device



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Finite Difference Time Domain Simulation of LCoS wavefront corrector



Chromatic effect in diffractive wavefront compensation

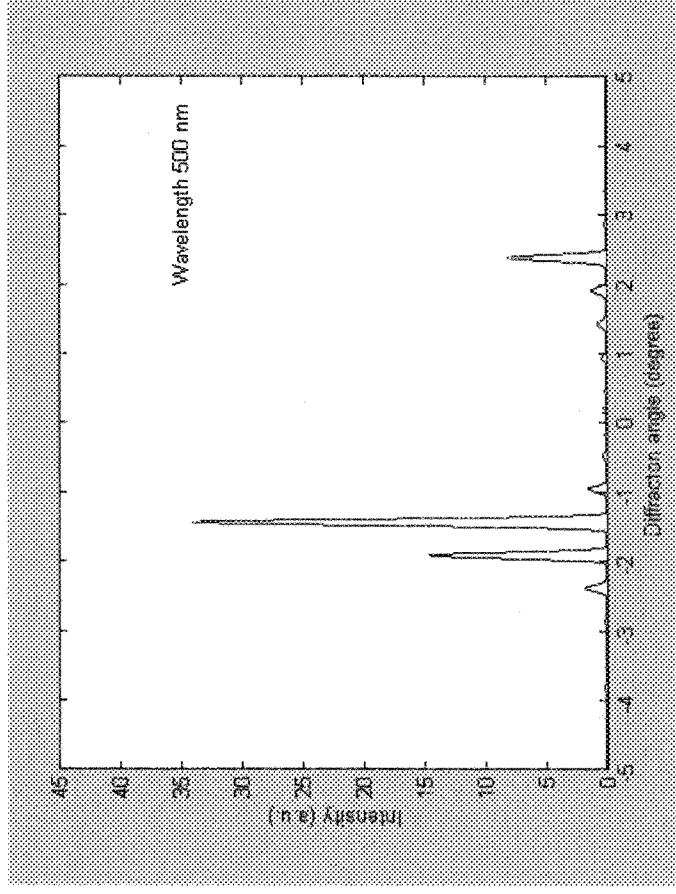
Chromatic effect depends strongly on correction magnitude

Choose Secondary peak <5% criteria

At maximum correction (125 waves)

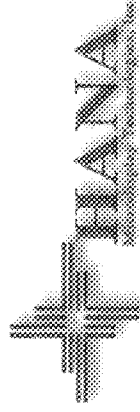
Bandwidth=50 nm*

* Agrees with Mark Grunisen's experimental results of a similar LC SLM system. SPIE Proc Vol. 5162, p172, 2003

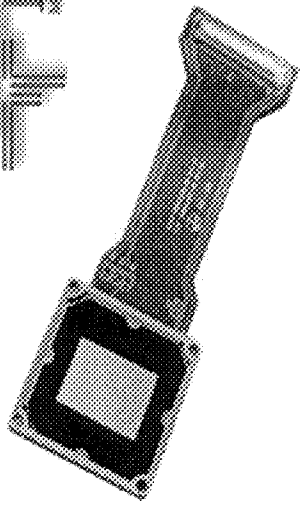


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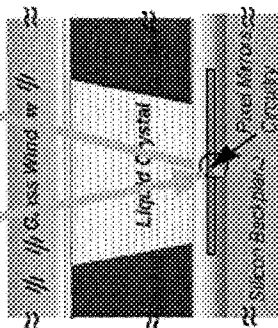
Liquid Crystal on Silicon Spatial light modulator



ISO 9002



Light IN
Image OUT
 (reflective devices)

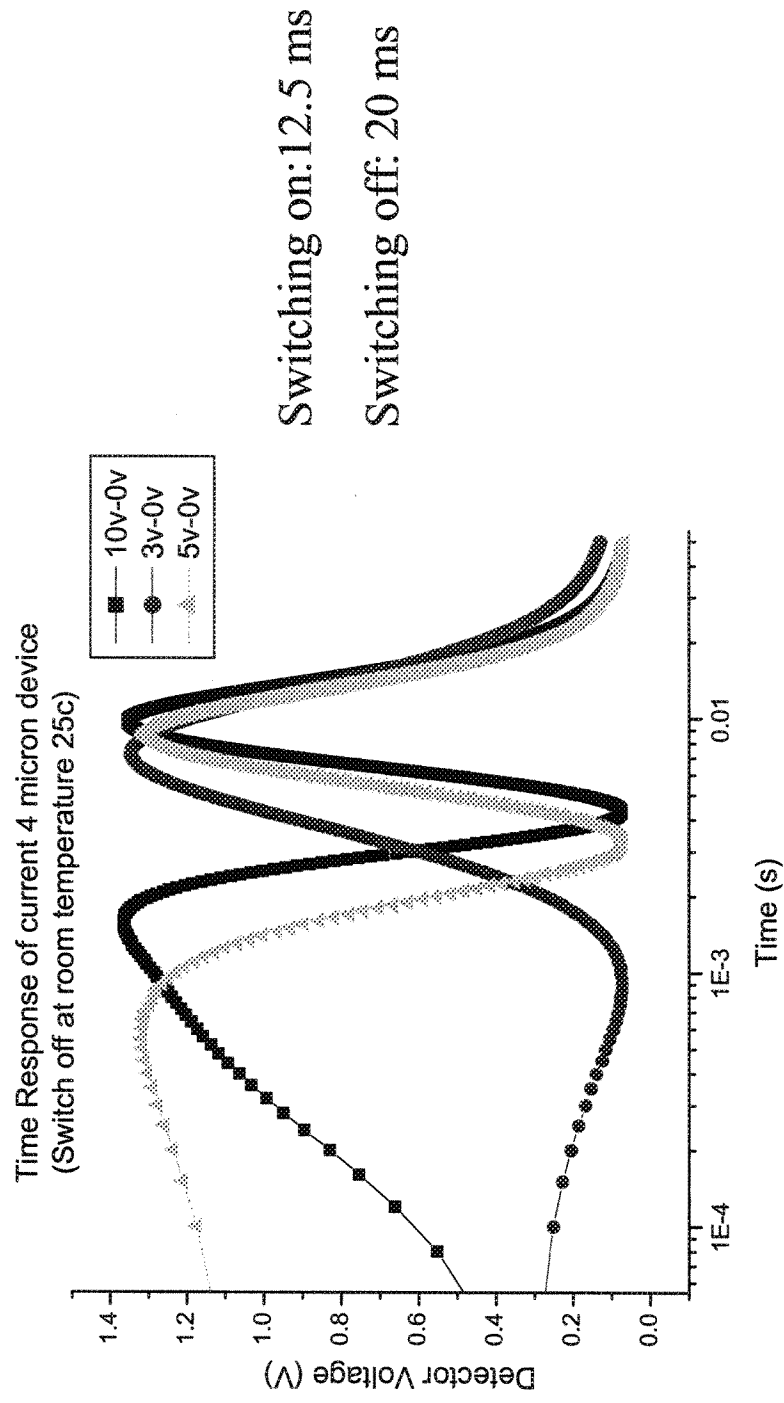


Liquid Crystal Display (LCD)

IC Backplane

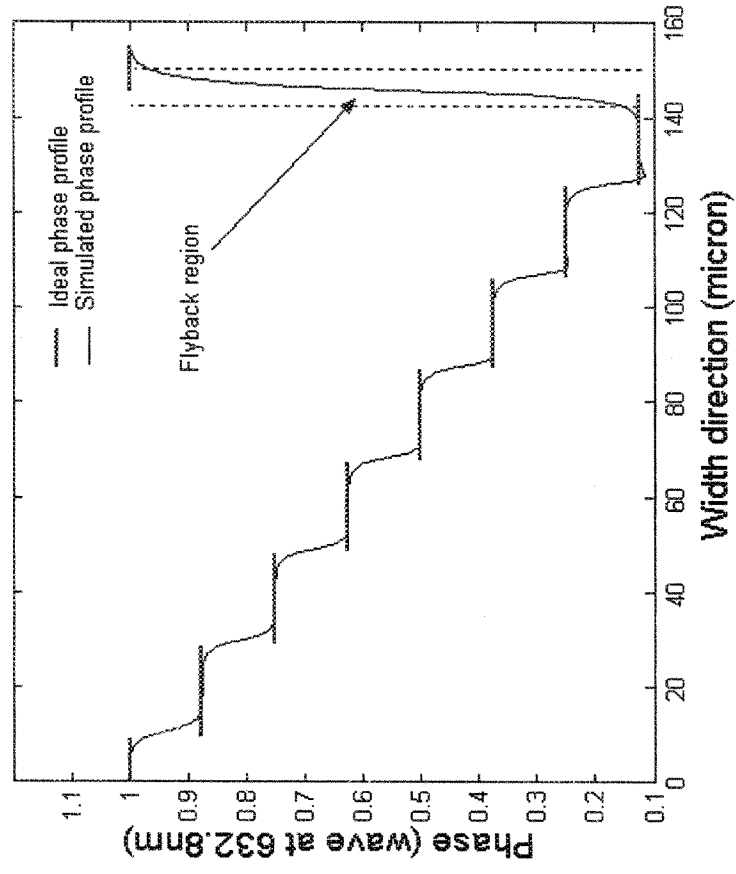
Resolution:	1024*768
Pixel Spacing:	19.4 m
Aperture:	20mm*15mm
Reflectivity:	80%
Filling factor:	96%
Speed:	50Hz, 25Hz, 5Hz
Effective stroke length:	0.7 m, 1.3 m, 2.5 m

Switching speed of LCoS



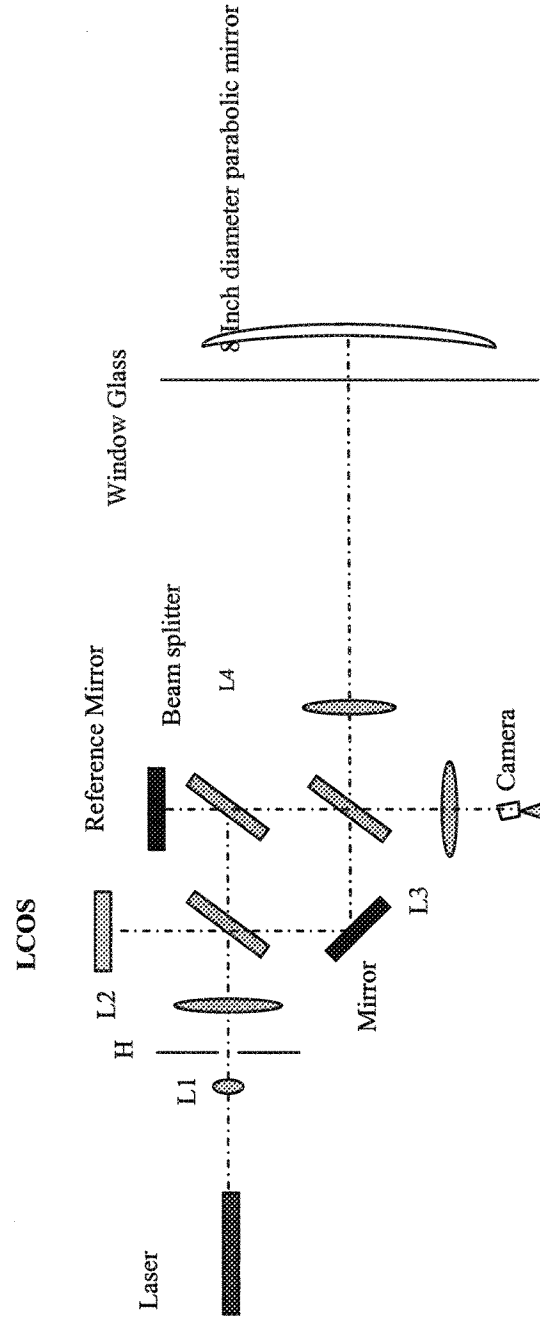
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Inter-pixel coupling is negligible



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Measurement and correcting system of aberration in 8 inch mirror.



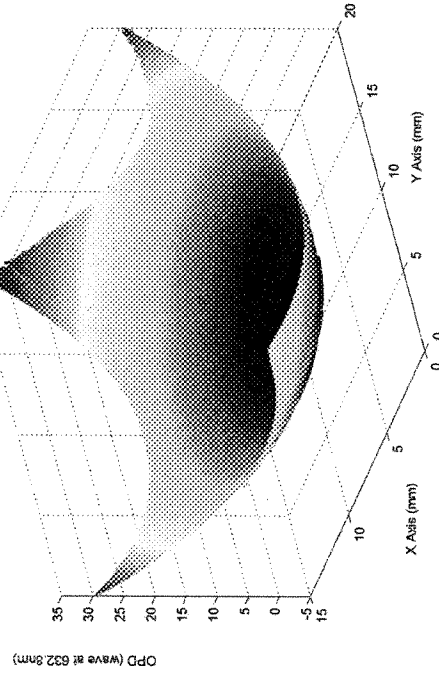
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Initial wavefront aberration in 8 inch telescope

Before correction:

34 waves of aberration P-V

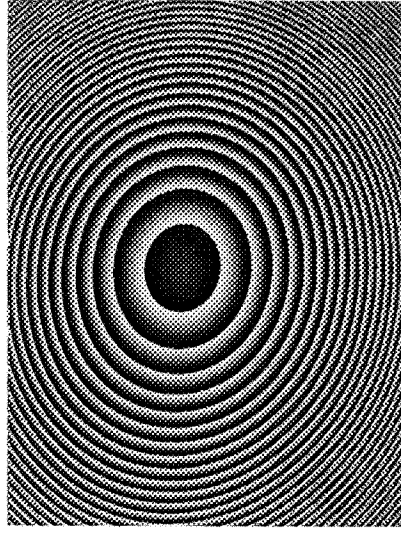
Strehl ratio 0.006



	Zernike term	Order	waves
1	Piston	0	7.781
2	Tilt	1	1.603
3	Tilt	1	-0.583
4	Focus	1	7.751
5	Astig.	2	2.097
6	Astig.	2	0.776
7	Coma	2	0.640
8	Coma	2	-0.130
9	Spherical	2	0.0783
10	Astig.	3	0.195
11	Astig.	3	-0.052
12		3	0.295
13		3	-0.031
14	Coma	3	0.056
15	Coma	3	-0.045
16	Astig.	3	-0.060

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Residual wavefront aberration

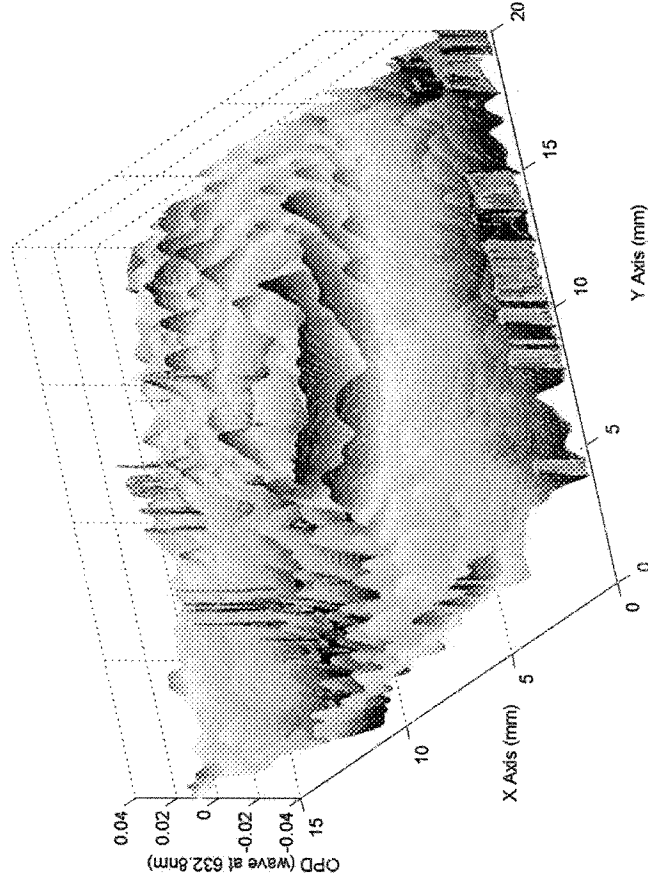


After correction:

1/10 wave of aberration P-V

Strehl ratio=0.83

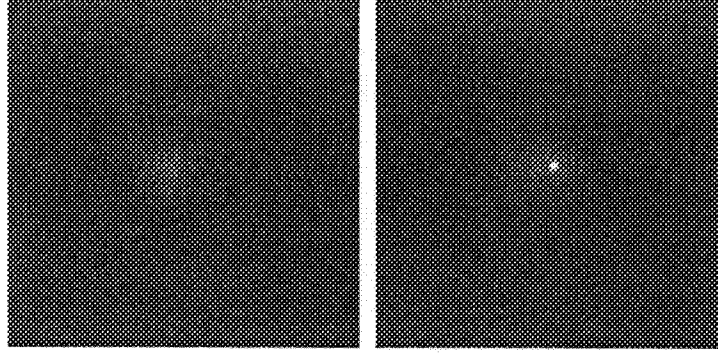
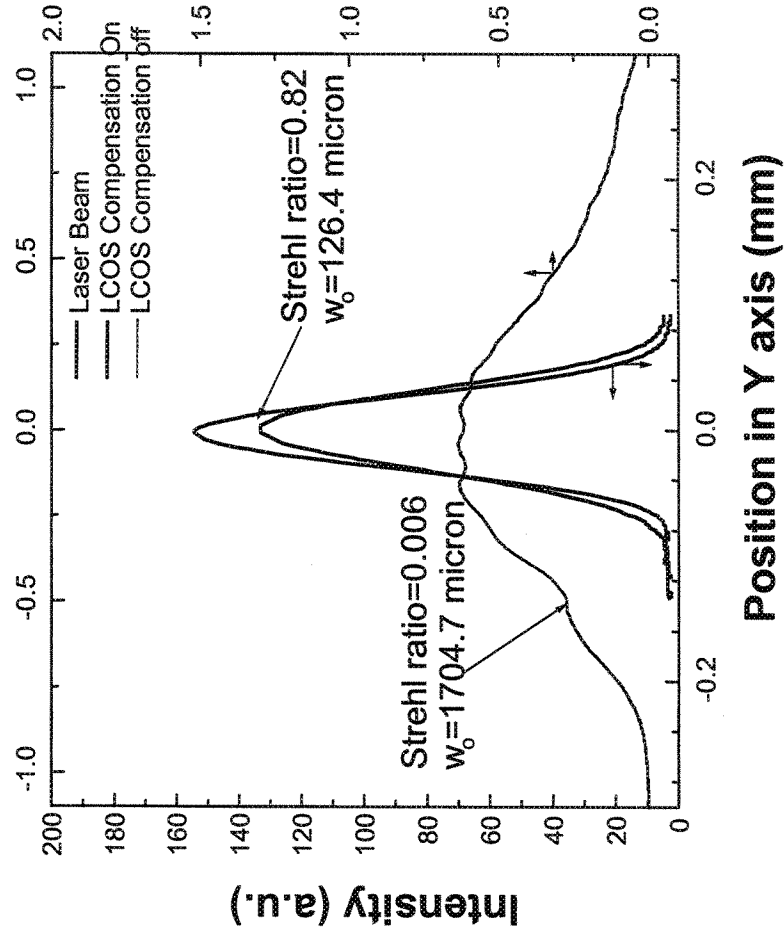
Diffraction limited performance!



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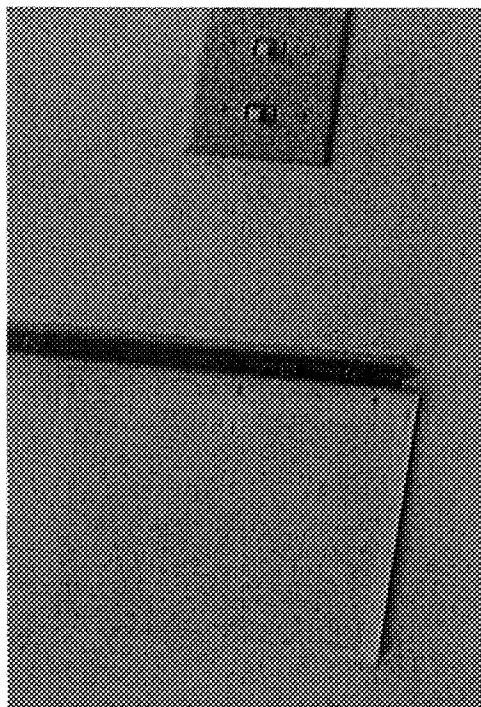
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Diffraction efficiency of wavefront compensation



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Conclusion

- LCoS SLM is capable of high efficiency wavefront compensation while offering:
 - <3k cost, ~1M resolution, correct arbitrary high order aberration, (up to 125 waves of tip-tilt or 60 waves P-V defocus)
- Enough speed (50Hz) for tracking movement of human eyes
- Chromatic effect strongly depends on magnitude of correction, at least 50 nm bandwidth is tolerable.
- LCoS SLM seems very suitable for aberration correction in human eyes. Very attractive for:

Obtaining diffraction limited retina image in human eyes,

Aberration simulator for patient to see the effect of refractive surgery.

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Acknowledgement

- Dr. Ronald Krueger, Cleveland Clinic

For kind encouraging us to present this work.

- Dr. Jim Schwiegerling, University of Arizona

For very helpful discussion regarding the application of LCoS in correction of wavefront aberration in human eyes.

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